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WATER QUALITY MONITORING IMPROVEMENTS
AT INDIANA DUNES

UNDERSTANDING AVALANCHES
IN GLACIER NATIONAL PARK

DETERMINING THE VOLUME OF THE
1889 JOHNSTOWN FLOOD

CLIMATE VARIABILITY AND ECOSYSTEM RESPONSE
IN WESTERN NATIONAL PARKS

REMOTE SENSING
FOR THE NATIONAL PARKS

EFFECTS OF WHITE-TAILED DEER ON VEGETATION
AT MANASSAS NATIONAL BATTLEFIELD PARK

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ON THE COVER

Swimmers enjoy summer sun, sand, and surf at Indiana Dunes National Lakeshore. Thanks to pioneering research by the U.S. Geological Survey and recent modernization in water quality monitoring, park users and managers now enjoy quicker and more reliable reports on water quality at popular swimming beaches where fecal contamination can be a problem. For more of the story, see page 19.

USGS/RICHARD WHITMAN

ADVANCES IN RECREATIONAL WATER QUALITY MONITORING at Indiana Dunes National Lakeshore

By Wendy Smith, Meredith Nevers, and Richard Whitman

Indiana Dunes National Lakeshore comprises more than 15,000 acres (6,075 ha) at the southern tip of Lake Michigan and serves more than 2 million visitors each year. Like all national parks, Indiana Dunes places a high priority on visitor safety. With miles of sandy beaches attracting hundreds of thousands of swimmers annually, attention to swimmer safety plays a big role in park management (fig. 1). Indiana Dunes has improved its ability to protect the health of swimmers through better science-based management and increased understanding of contaminants. Most research has focused on *Escherichia coli* and its nature, sources, and distribution because it is widely accepted as an indicator of potential pathogens. Though research on *E. coli* and recreational water quality is continually generating new information, public beach managers may gain valuable insight into this management issue from our experience at Indiana Dunes. This article reviews one of the longest maintained indicator bacteria monitoring programs in the National Park System, highlights lessons learned, and summarizes research findings that may be of interest to public beach managers.

Figure 1. More than 2 million people per year visit Indiana Dunes National Lakeshore with hundreds of thousands enjoying the sandy swimming beaches. The timely and accurate measurement of water quality to protect swimmers' health has long been a problem for park managers. USGS/KASIA PRZYBYLA-KELLY

E. coli as an indicator of beach water quality

Indiana Dunes swimming beaches occasionally receive waste from wildlife and domestic animals, boat discharge, septic systems, and combined sewer overflows. Because water containing sewage may include a variety of disease-causing agents (e.g., parasites, bacteria, and viruses), managers need to monitor beach water quality. Accordingly, staff at Indiana Dunes National Lakeshore has been monitoring the water quality at its beaches since 1979.

E. coli is a bacterium present in the gastrointestinal tracts of humans and other warm-blooded animals. It serves as an indicator bacterium because, though it is generally harmless (Geldreich 1978), its presence is associated with fecal contamination and human pathogens (Cabelli et al. 1979).

According to the Beaches Environmental Assessment and Coastal Health Act (BEACH) of 2000, all states must adopt the U.S. Environmental Protection Agency's (EPA) established water quality criteria for monitoring bacteria. For freshwater, the strictest federal criterion—adopted by Indiana—is that no single sample should exceed 235 colony forming units (CFU) of essentially culturable *E. coli* per 100 ml (3.4 fl oz) of water, or a geometric mean of 126 CFU/100 ml over the course of 30 days. According to Indiana standards, if this level is exceeded, beach managers should issue a swimming advisory.

Until 2004, staff at Indiana Dunes regularly monitored for *E. coli* once a week and closed national lakeshore waters to swimming if levels were above the EPA standard. Sampling was generally conducted on Thursdays in an attempt to know *E. coli* levels before weekend beachgoers arrived and therefore protect swimmers.

Ongoing research at Indiana Dunes during that time led to the interesting discovery that *E. coli* may not always be an effective indicator of water quality. Though this bacterium is found in the intestines of warm-blooded animals, scientists discovered that it can also persist and perhaps thrive in many other natural environments (Whitman and Nevers 2003).

E. coli may not always be an effective indicator of water quality.

Research conducted by the U.S. Geological Survey (USGS) has shown that temperate forest soils in the watershed of Dunes Creek (a Lake Michigan tributary within the Indiana Dunes State Park, which is encompassed by the national lakeshore) harbor *E. coli* throughout the entire year. The persistently high *E. coli* counts in the creek itself may be due to sediment-borne bacteria eroding into the water. In these cases, there was no significant human fecal input, yet *E. coli* was present (Byappanahalli et al. 2003).

E. coli have also been found year-round in the shore sand as far from the shoreline as the foredunes, making the sand a non-point and generic source of *E. coli* contamination to the beach water. When waves strike the beach they churn up the sand and carry *E. coli* into the water. Research has shown that *E. coli* counts in nearshore and submerged sand are typically several orders of magnitude higher than in the beach water (Whitman and Nevers 2003). Although visitor contact with contaminated sand may be more common if beach water is closed to swimming, the health effects of *E. coli* presence in sand are unknown.

E. coli are also present on the green alga *Cladophora*, which often amasses along the Lake Michigan beaches and harbors high densities of the bacterium (Whitman et al. 2003). In a recent study, mean concentrations of *E. coli* per gram (0.04 oz) of *Cladophora* were 10,000 CFU. Wave action can wash *E. coli* from *Cladophora,* increasing the likelihood of a beach closure (Whitman et al. 2003).

Researchers and resource managers are now recognizing that *E. coli* are much more common in the natural environment than previously suspected. A recent study even found *E. coli* in the fluid of bog-dwelling pitcher plants (Whitman et al. 2005). Not only can *E. coli* exist in these various environments, but recent studies also indicate that, in some areas, they can actually reproduce. In one research project at Indiana Dunes State Park, hot water was used to treat the forest soil, killing off all but extremely small numbers of *E. coli*. After the heat treatment, not only did the bacteria grow back, but they persisted in the test plot for more than a year afterward (Byappanahalli et al. 2002).

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These naturally occurring reservoirs of *E. coli* exist in the seeming absence of fecal material and lead to questions about *E. coli*'s suitability as an indicator of fecal contamination. In many cases, today's beach managers may decide to close a beach when naturally occurring *E. coli*, as opposed to *E. coli* from a contamination event, are present. Because *E. coli* appear to be naturally abundant and generally harmless, unless a combined sewer overflow or another known source of human sewage input has occurred, many beach closures are likely unnecessary for protecting public health. The actual source of the *E. coli* and the concomitant presence of pathogens still need to be determined.

Shortcomings of *E. coli* monitoring methods

Monitoring methods for *E. coli* also are problematic for beach managers. Traditional monitoring practices rely on culturing *E. coli* from water samples collected at the beach, and results are not available until 18–24 hours after sampling. By then the bacteria levels in the beach water may have changed significantly, and the beaches are either closed too late to protect visitor health or the closures are unnecessary. In fact, many studies show little or no correlation between indicator levels from the sampling day to the next day when the results are used by managers to make decisions about beach closures (Whitman et al. 1999) (fig. 2).

In 2004, staff at Indiana Dunes National Lakeshore tested its beaches five to seven days per week to help researchers improve their understanding of the environmental conditions associated with high bacteria levels (for example, caused by heavy rains). That summer, though 33 water samples exceeded the water quality standard, only three of those exceedances occurred on consecutive days. According to Scott Hicks, assistant chief of Resource Management at Indiana Dunes, "It is only when consecutive exceedances occur that issuing a swimming advisory based on the previous day's sample correctly warns the public of high bacteria levels." This means that only 9% of the closures in 2004 accurately reflected *E. coli* levels that truly exceeded the EPA standard. The rest of the time, thousands of people may have been kept out of the water unnecessarily.

On the other hand, every water quality report suggesting a beach closure indicates that on the prior day, if the beaches were open, people were swimming in water that exceeded the standard for safe swimming. This happened 30 times in 2004 when samples exceeded the water quality standard.

Test results not only vary from one day to the next, but studies in Lake Michigan and a marine beach in California also show that fecal indicator bacteria levels can vary substantially over very short distances (from centimeters to meters) and over short time periods (from minutes to hours) (Boehm et al. 2002, Whitman and Nevers 2004). Water samples collected in the morning can have high counts although the water may be safe for swimming a few hours later as *E. coli* CFU counts fall below the EPA limit. This pattern has commonly been attributed to disinfection by sunlight, which kills *E. coli* cells or makes them non-culturable (Whitman et al. 2004). Whereas the vast majority of beach managers sample their water in the morning—before the potential for sunlight disinfection—*E. coli* counts are often lower in the afternoon, making the time of sampling an important component of the monitoring program. If they sampled in the afternoon the *E. coli* levels might be below the 235 CFU/100 ml closure level.

E. coli densities also vary significantly with water depth, with higher counts in shallow water rather than in deep water (Whitman and Nevers 2004). In one study on 63rd Street Beach in Chicago, researchers learned that at least six water samples would have to be taken at a single location to achieve 70% precision around the 235 CFU/100 ml level (Whitman and Nevers 2004). Unfortunately, only a single sample is collected at most beaches. In these cases, the samples do not represent the high variation inherent in beach water, and will likely grossly over- or underestimate the actual *E. coli* count.

Improving advisory accuracy

Each day that a beach is closed may prevent swimmers from becoming ill, but it also causes loss of valuable recreational access. On any given day, the net effect of this trade-off depends on the level of contamination and health risk that actually exists, how many people were exposed to the water, and what the management decision was for that day. Rabinovici et al. (2004) describe a method for evaluating the effectiveness of swim-closure policies in terms of the overall costs and benefits to swimmers. Results from that case study involving four summers (1998–2001) of water quality and visitor use data from Indiana Dunes State Park beach showed that nearly two-thirds of swim closures based on *E. coli* levels were unnecessary. According to Bob Daum, chief of Resource Management at Indiana Dunes National Lakeshore, "The public needs more information. They need a method to help them make an informed decision rather than having to rely on a beach being designated as open or closed based on a system shown to be inaccurate."

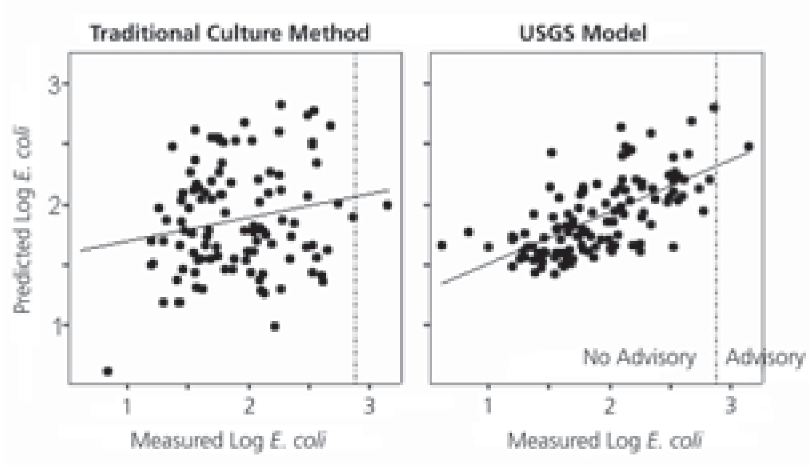

Figure 2. The current model uses yesterday's *E. coli* level to estimate current swimming conditions (left). The USGS model, SAFE (right), uses lake and weather conditions, such as cloud cover, wave height, turbidity, and lake current direction and speed to estimate near real-time water quality. The USGS model explained about 10 times more variance than the current EPA approach.

Future directions

In 2005, the U.S. Geological Survey initiated a pilot project at one of the most popular Indiana Dunes beaches that considered a completely new way of determining *E. coli* concentration in the water. Through Project SAFE (Swimming Advisory Forecast Estimate), *E. coli* concentration was estimated using surrogate parameters such as wind direction, water turbidity, and the quality of water in a nearby river outfall (fig. 3). In 2006, Project SAFE is being used for managing five beaches in Lake and Porter Counties, including one at Indiana Dunes National Lakeshore, that are directly affected by contaminants, particularly during prevailing north winds (fig. 4).

Further, in association with Project SAFE in 2006, the U.S. Geological Survey will test a more rapid means of analyzing microbiological water quality using quantitative PCR (polymerase chain reaction). PCR is a

Water samples collected in the morning can have high counts although the water may be safe for swimming a few hours later.

Figure 3. Kasia Przybyla-Kelly from the USGS Lake Michigan Ecological Research Station takes water quality samples at Indiana Dunes. Samples are analyzed for turbidity and are used for the prediction of *E. coli* levels. USGS/DAWN SHIVELY

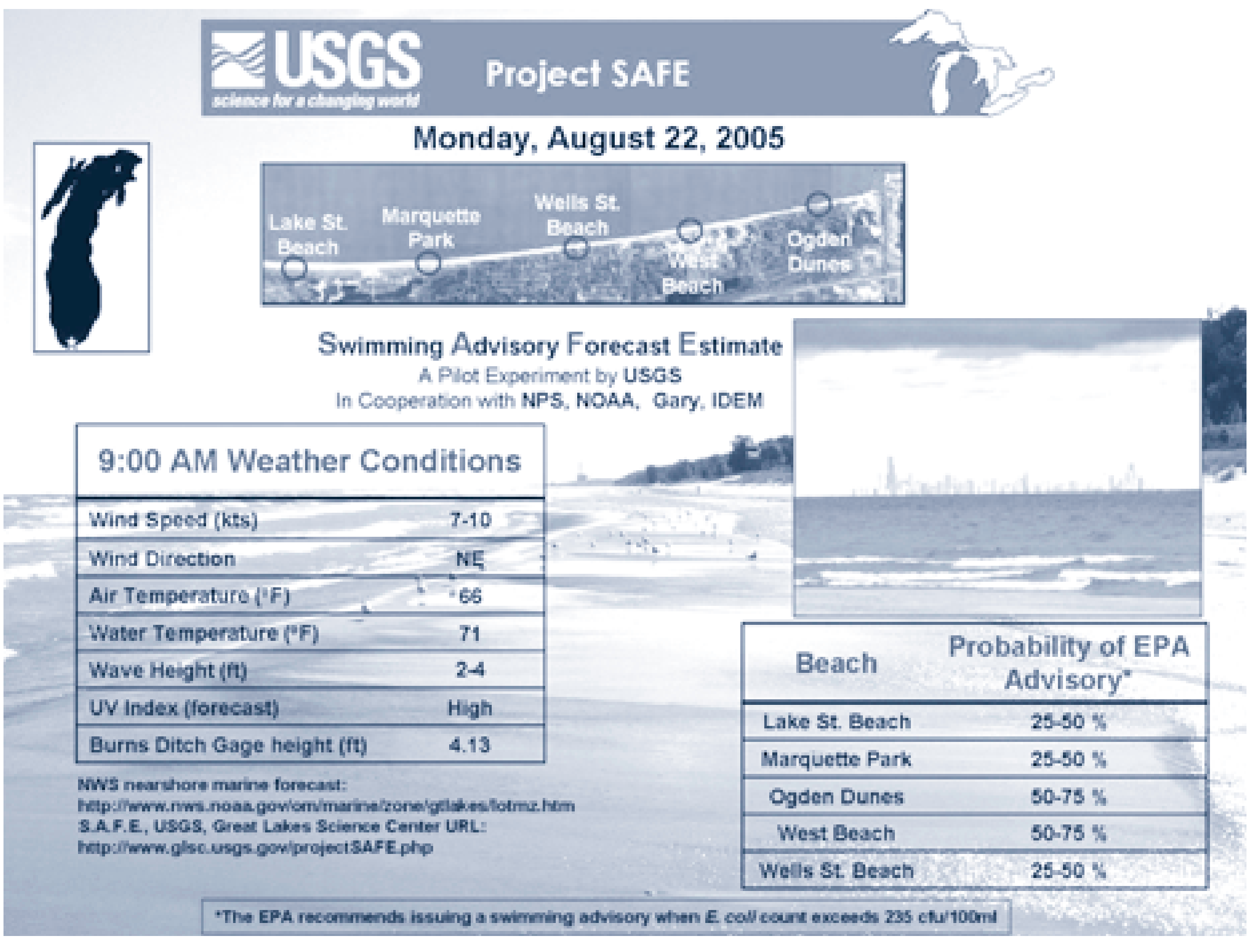

Figure 4. A sample Web output screen from Project SAFE. This model developed by Richard Whitman and Meredith Nevers, U.S. Geological Survey, predicts the *E. coli* every weekday by 10 am. Beach advisory predictions are e-mailed to area managers and can be accessed from the USGS Web site (http://www.glsc.usgs.gov/ProjectSAFE.php) by following Internet links from local newspapers. The insert shows a view of Chicago from Indiana Dunes National Lakeshore on the day of the forecast.

Figure 5. Experiments are under way at the park to determine the concentration of enterococci, a fecal coliform bacteria, using quantitative PCR. This technique can potentially measure fecal indicator bacteria in less than two hours compared to the 24-hour test now in use.
NPS/WENDY SMITH

molecular process used by biologists to replicate DNA in order to identify the genetic characteristics of an organism (fig. 5). In quantitative PCR this reaction is designed for one organism, in this case the bacterium *Enterococcus faecalis*, an indicator of fecal contamination. Scientists take water samples, extract DNA from the bacteria, and measure DNA replication over a short period of time. In just a few hours—instead of the usual 18–24 hours needed for traditional culturing—they are able to count the concentration of the bacteria, relate it to the concentration in the original sample, and determine the public health risk. This technique will enable managers to learn of water quality conditions that morning, in time to issue accurate swimming advisories for the day. This is a trial application of this method, but the hope is that some day a technique can be developed to directly measure the presence of pathogens in swimming water and give managers real-time indications of the recreational water quality of beaches.

The recent success of the Indiana Dunes beach management program has been possible only through the pioneering, park-based research of the U.S. Geological Survey in cooperation with state and local agencies. This collaborative experience has shown how historical data, diligence, and commitment to science-based management and research can improve visitor safety and enhance enjoyment of the park.

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